STUDY ON THE PERFORMANCE OF NEWTON – RAPHSON LOAD FLOW IN DISTRIBUTION SYSTEMS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF TECHNOLOGY IN ELECTRICAL ENGINEERING

By

ARADHANA PRADHAN (108EE069)

PADMAJA THATOI (108EE013)

Under the supervision of

Prof. Sanjib Ganguly

Department of Electrical Engineering

National Institute of Technology, Rourkela

May 2012

CERTIFICATE

This project report has been written by ourselves.

Aradhana Pradhan **Padmaja Thatoi**

108EE069 **108EE013**

Certified that the students have performed the project work under my supervison.

Signature of the Supervisor

Prof. Sanjib Ganguly

Department of Electrical Engineering

ACKNOWLEDGEMENTS

We would like to express our heartiest gratitude and sincere thanks to our mentor and project guide Prof. Sanjib Ganguly, Department of Electrical Engineering, National Institute of Technology, Rourkela for providing us the necessary guidance to carry out the project work. We thank him for his constant support, encouragement and helpful suggestions throughout our project work which would not have been possible without his guidance and motivation.

Further, we would like to thank all the administrative staff members of Department of Electrical Engineering of NIT Rourkela for their earnest cooperation and support. We also wish to take this opportunity to thank all others who were a constant and active source of encouragement throughout our endeavour.

Aradhana Pradhan

(Roll No. 108EE069)

Padmaja Thatoi

(Roll No. 108EE013)

ABSTRACT

The reliability of the Newton-Raphson (NR) approach of Load Flow Solution is comparatively better than the other load flow techniques, as unlike other methods it can solve cases that lead to divergence, but the NR method too has some limitations. It has been observed that this method fails under some ill-conditioned situations. The distribution systems usually fall into the category of ill-conditioned power systems. Experience of such failures while applying the NR method in distribution systems encourages investigation of various ways of improving the reliability of the NR approach. Hence, the objective of this project is to study the application of NR method in load flow studies and determine the various difficulties faced while using the method for physically feasible problems, particularly in distribution systems.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

CHAPTER I: INTRODUCTION

The state of a power system and the methods of calculating this state are very important in evaluating the operation and control of the power system and the determination of future expansion for this system. The state of any power system can be determined using load flow analysis that calculates the power flowing through the lines of the system. There are different methods to determine the load flow for a particular system such as: Gauss-Seidel, Newton-Raphson Load, and the Fast-Decoupled method.

Over the past few years, developments have been made in finding digital computer solutions for power-system load flows. This involves increasing the reliability and the speed of convergence of the numerical-solution techniques. In routine use, even few failures to give first-time convergence for physically feasible problems can be uneconomical. Hence, the Newton-Raphson (NR) approach is the most preferred general method.

The characteristics and performance of transmission lines can vary over wide limits mainly dependent on their system. Hence, the NR method is used to maintain an acceptable voltage profile at various buses with varying power flow.

The transmission system is loop in nature having low R/X ratio. Therefore, the variables for the load–flow analysis of transmission systems are different from that of distribution systems which have high R/X ratio. Thus, unlike in distribution systems NR method is satisfactorily used for load flow studies in transmission systems [1].

CHAPTER II: BACKGROUND AND LITERATURE REVIEW

The main purpose of the load-flow solution is to evaluate the individual phase voltages at all busbars/buses connected to the network corresponding to specified system conditions. As the active and reactive powers, voltage magnitudes, and angles are involved for each bus four independent constraints are required to solve for the above mentioned four unknowns parameters. There are two main types of buses, i.e., load and generator buses. A special type of generator bus is used as reference bus and is named as slack bus. For different types of buses the constraints are different [2], [3].

The Newton-Raphson approach is the most preferred load flow method because of its various advantages. It has powerful convergence characteristics compared to alternative processes and considerably low computing times are achieved when the sparse network equations are solved by the technique of sparsity-programmed ordered elimination [4]. The NR approach is particularly useful for large networks as computer storage requirements are moderate and increase with problem size almost linearly. The method is very sensitive to a good starting condition. The use of a suitable starting condition reduces the computation time remarkably, as well as ensures the convergence. No acceleration factors have to be determined, the choice of slack bus is rarely critical, and network modifications require quite less computing effort. The NR method has great generality and flexibility, hence enabling a wide range of representational requirements to be included easily and efficiently, such as onload tap-changing and phase-shifting devices, area interchanges, functional loads and remote voltage control. The NR load flow is central to many recently developed methods for the optimisation of power system operation, sensitivity analysis, system-state estimation, linear-network modelling, security evaluation and transient-stability analysis, and it is well suited to online computation [5].

NR Load Flow in Distribution Systems

The distribution systems usually fall into the category of ill-conditioned power systems for generic Newton-Raphson like methods with its special features, such as [6], [7]:

i. Radial or weakly meshed topologies

Most of the distribution systems are radial or weakly meshed types. The increase in requirements for reliability and outgoing distribution generation has made the structure of distribution systems more complex. Therefore, the power flow analysis in such distribution systems has become more difficult [8].

ii. High R/X ratio of the distribution lines

Transmission networks are composed mainly of overhead lines thus, the ratio is usually lower than 0.5. In distribution networks where both overhead lines and cables are used, the *R/X* ratio is high ranging from 0.5 to as high as 7, where high ratio values are typically for low-voltage networks.

iii. Unbalanced operation

Three-phase unbalanced orientation greatly increases the complexity of the network model, since phase quantities have to be considered including mutual couplings [9].

iv. *Loading conditions*

Most of the load flow methods were developed assuming a static load model. But, a practical load model is required for getting reliable results.

v. Dispersed generation

Distributed generation is being increasingly used to meet the fast load increase in the deregulation era. The utilities have to analyse the operating conditions of the radial-type systems with distributed sources [10].

vi. Non-linear load models

Widespread use of non-linear loads such as, rectifiers in distribution system distorts the current drawn from the source.

Usually the commercial SCADA/DMS systems treat these distribution systems as independent parts, i.e., HVAC (high voltage a.c.) loop and MVAC (medium voltage a.c.) or LVAC (low voltage a.c.) radial systems. Such rough equivalence will cause inaccuracies in the power flow solutions.

Figures

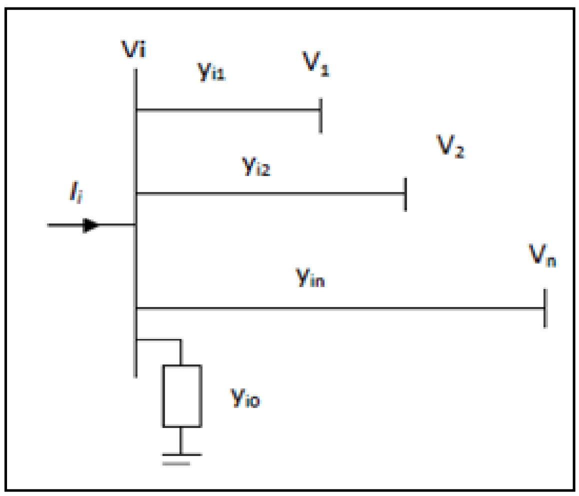


Fig.2.1: A typical bus of the power system

Equations

Referring to the above figure, power flow equations are formulated in polar form for the n-bus system in terms of bus admittance matrix Y as:

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \qquad \text{.....................(1)}$$

where, i,j are to denote i^{th} and j^{th} bus.

Expressing in polar form:

$$I_i = \sum_{j=1}^{n} |V_{ij}||V_j| \angle\theta_{ij} + \delta_j \qquad \text{………………(2)}$$

The current can be expressed in terms of the active and the reactive power at bus *i* as:

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad \text{......................(3)}$$

Substituting for I_i from eqn.(3) in eqn.(2):

$$P_i - jQ_i = |V_i|\angle - \delta_i \sum_{j=1}^{n} |V_{ij}||V_j| \angle\theta_{ij} + \delta_j \qquad \text{..................(4)}$$

Separating the real and imaginary parts:

$$P_i = \sum_{j=1}^{n} |V_i||V_j||V_{ij}| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) \qquad \text{........................(5)}$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||V_{ij}| \sin\left(\theta_{ij} - \delta_i + \delta_j\right) \qquad \text{……………..(6)}$$

Expanding eqns. 5 & 6 in Taylor's series about the initial estimate neglecting higher order terms, we get:

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{c|c} \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \end{pmatrix} \\ \hline \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{pmatrix} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta \left|V_2^{(k)}\right| \\ \vdots \\ \Delta \left|V_n^{(k)}\right| \end{bmatrix} \qquad \text{……………(7)}$$

The Jacobian matrix gives the linearized relationship between small changes in $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta[V_i^k]$ with the small changes in real and reactive power $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \quad ....(8)$$

The diagonal and the off-diagonal elements of J1 are:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j\neq i} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \quad ....(9)$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \quad ....(10)$$

Similarly we can find the diagonal and off-diagonal elements of ***J2, J3*** and ***J4.***

The terms $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are the difference between the scheduled and calculated values, known as the power residuals.

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \quad ....(11)$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \quad ....(12)$$

Using the values of the power residuals and the Jacobian matrices, $\Delta\delta_i^{(k)}$ and $\Delta|V_i^{(k)}|$ are calculated from the equation (7) to complete the particular iteration and the new values calculated as shown below are used for the next iterations [2].

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \quad ....(13)$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \quad ....(14)$$

CHAPTER III: METHODOLOGY

This work essentially requires the detailed study of the various limitations of the NR method applied to the distribution system networks. The main approach of this paper will be implementation of the developed NR load flow method with starting from simple power systems to complex ill-conditioned systems and investigation of its increasing complexity.

The above formulation of Newton-Raphson method of load flow solution is implemented through MATLAB programming. The Newton-Raphson program is tested on various IEEE test bus systems designed as transmission systems and distribution systems.

The IEEE bus systems used in this project work are:

1. IEEE 30-Bus Test System
2. IEEE 13-Node Test Feeder
3. IEEE 38-Node Test System

The IEEE 30-Bus Test System is used for transmission system analysis and the other two test systems are used for distribution system analysis.

The general procedure includes finding the range of R/X ratio for the test systems so that the effect of the ratio on the behaviour of the system can be analysed through the Newton-Raphson MATLAB program.

Through this analysis the susceptibility of the systems to the change in R/X ratio of a single line or a set of lines can be judged by the maximum power mismatch and the number of iterations required by the system to converge using the Newton-Raphson program.

Thus each test system implemented in the MATLAB program is examined through tables and graphical representations of the results obtained.

CHAPTER IV: APPLICATION IN TRANSMISSION SYSTEM

The IEEE 30-Bus Test System data is used as input in the program to generate the load flow solution as shown below.

The R/X ratio of the various lines in the IEEE 30-bus system ranges from 0.3 to 1.20. The Newton-Raphson method is successfully implemented for this system as the R/X ratios lied between a convenient range of convergence. But practically, distribution systems are ill-conditioned systems with high R/X ratios ranging from 0.5 to 7.0. Hence, the line data for the prescribed IEEE 30-bus is suitably modified to increase the value of R/X ratio:

a) For individual lines taken one at a time

   The R/X ratio for each line is increased by a factor starting from 1 to 10 and the number of iterations required by the Newton-Raphson method to converge for each case is determined. The study of the convergence characteristics of each line with respect to its R/X value gives the susceptibility of the line to its higher value of R/X ratio. This also shows the effect of increase in R/X value of each line on the entire distribution system. The cases which lead to non-convergence of the Newton- Raphson method are represented by the symbol 'NC' in the above mentioned MATLAB program. The graph depicting the number of iterations versus the increment factor of R/X value is plotted.

b) For a set of 5 lines taken at once

   The R/X ratio is increased simultaneously for a set of five consecutive line data by a factor starting from 1 to 7.

Comparison of the results obtained in both case taking one line at a time and taking five lines at once is done to study the convergence of the NR method when large number of lines with higher R/X values are involved.

CHAPTER V: APPLICATION IN DISTRIBUTION SYSTEM

The Newton-Raphson method of load flow solution is implemented through MATLAB programming using the IEEE 13-node Test Feeder data and 38-node Test System data as input in the program to generate the load flow solution as shown below.

IEEE 13-Node Test Feeder:

The R/X ratio of the buses in the IEEE 13-node bus system ranges from 0.18 to 0.52. But practically, distribution systems are ill-conditioned systems with high R/X ratios ranging from 0.5 to 7.0. Hence, the line data for the prescribed IEEE buses are suitably modified to increase the value of R/X ratio:

For the three phase 13-node test feeder data, the equivalent values for single-phase system are calculated for the convenience of its use in the MATLAB program for load flow solution.

The calculations are as follows:

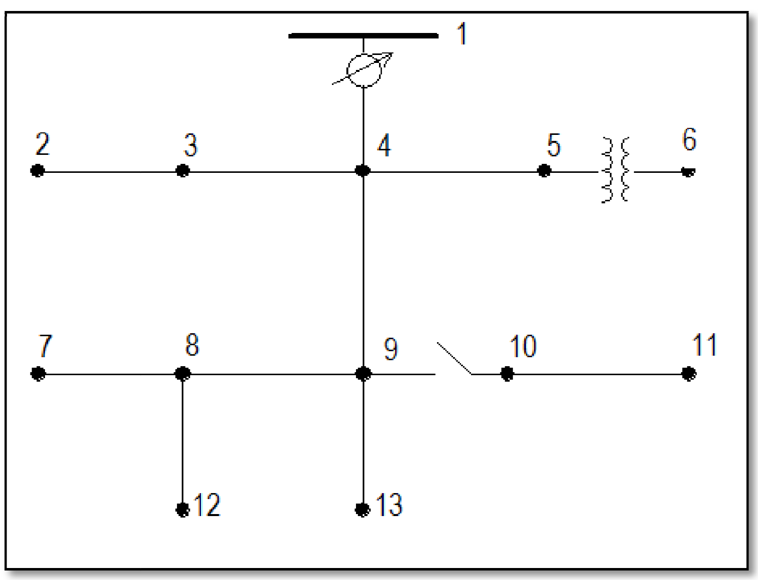


Fig.5.1: IEEE 13 Node Test Feeder system

Line Segment Data:

Node A	Node B	Length(ft.) 1ft=(1/5280)miles	Config.	R+jX
4	3	500	603	0.1256+0.1280j
4	5	500	602	0.0708+0.1133j
5	6	0	XFM-1	0
3	2	300	603	0.0754+.0768j
1	4	2000	601	0.1295+0.3915j
8	12	800	607	0.2034+0.0776j
4	9	2000	601	0.1295+0.3915j
9	8	300	604	0.0754+.0768j
9	13	1000	601	0.0673+0.1957j
9	10	0	Switch	0
8	7	300	605	0.0755+0.0766j
10	11	500	606	0.0753+0.0409j

Transformer Data:

	kVA	kV-high	kV-low	R - %	X - %
Substation:	5,000	115 – D	4.16 Gr. Y	1	8
XFM -1	500	4.16 – Gr.W	0.48 – Gr.W	1.1	2

Capacitor Data:

Node	Ph-A	Ph-B	Ph-C
	KVAr	kVAr	kVAr
11	200	200	200
7			100
Total	200	200	300

Spot Load Data:

Node	Load	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3	AVG	AVG
	Model	kW	kVAr	Kw	kVAr	kW	kVAr	KW	KVAR
6	Y-PQ	160	110	120	90	120	90	133.333	96.667
3	Y-PQ	0	0	170	125	0	0	170	125
2	D-Z	0	0	230	132	0	0	230	132
12	Y-Z	128	86	0	0	0	0	128	86
9	D-PQ	385	220	385	220	385	220	385	220
11	Y-PQ	485	190	68	60	290	212	281	154
10	D-I	0	0	0	0	170	151	170	151
7	Y-I	0	0	0	0	170	80	170	80
	TOTAL	1158	606	973	627	1135	753	1667.33	1044.67

Distributed Load Data:

Node A	Node B	Load	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3
		Model	kW	kVAr	kW	kVAr	kW	kVAr
4	9	Y-PQ	17	10	66	38	117	68

(R+jX) for different configurations (in ohms per mile)

601: 0.3418+1.0335j

602: 0.7479+1.1969j

603: 1.3266+1.3520j

604: 1.3266+1.3520j

605: 1.3292 + 1.3475j

606: 0.7952 + 0.4322j

607: 1.3425 + 0.5124j

After the calculations the bus data and the line data are appropriately fed to the MATLAB program as the input and the load flow solution for the 13-node feeder system is determined.

The R/X ratio of the lines in the IEEE 13-node system lied between a convenient range of convergence from 0.12 to 0.52. Hence the Newton-Raphson method is successfully implemented for this system. The R/X ratio of the lines is increased by a factor ranging from 1 to 20 in two different manners:

a) Individual lines taken one at a time

The R/X ratio for each line is increased and the number of iterations required to converge as well as the maximum power mismatch at the end are noted for each case. For this system, as the no. of iterations does not change with the R/X ratio, the convergence characteristics of each line with respect to its R/X value is studied using the graphical representation of maximum power mismatch values.

b) A set of 5 lines taken at once

The R/X ratio is increased simultaneously for a set of five consecutive line data by a factor starting from 1 to 20.

A comparison of the susceptibility of the lines to its higher value of R/X ratio is done using the plots of the maximum power mismatch.

IEEE 38-Node Test System:

The R/X ratio of the lines in the IEEE 38-node system ranges from 0.04 to 1.00. The Newton-Raphson method is successfully implemented for this system as the R/X ratios lied between a convenient range of convergence. Hence, the line data for the IEEE 38-node system is suitably modified to increase the value of R/X ratio. The R/X ratio for the lines is increased by a factor starting from 1 to 20 and the study of the convergence characteristics is done using the number of iterations required to converge and maximum power mismatch. Also the graphical representations are used for comparisons.

CHAPTER VI: RESULTS AND DISCUSSION

1) TRANSMISSION SYSTEM

Newton-Raphson load flow solution for the IEEE 30-bus system using the MATLAB program:

Power Flow Solution by Newton-Raphson Method

Maximum Power Mismatch = 7.54898e-007

No. of Iterations = 4

Bus	Voltage	Angle	------Load------		---Generation---		Injected
No.	Mag.	Degree	MW	Mvar	MW	Mvar	Mvar
01	1.060	0.000	0.000	0.000	260.998	-17.021	0.000
02	1.043	-5.497	21.700	12.700	40.000	48.822	0.000
03	1.022	-8.004	2.400	1.200	0.000	0.000	0.000
04	1.013	-9.661	7.600	1.600	0.000	0.000	0.000
05	1.010	-14.381	94.200	19.000	0.000	35.975	0.000
06	1.012	-11.398	0.000	0.000	0.000	0.000	0.000
07	1.003	-13.150	22.800	10.900	0.000	0.000	0.000
08	1.010	-12.115	30.000	30.000	0.000	30.826	0.000
09	1.051	-14.434	0.000	0.000	0.000	0.000	0.000
10	1.044	-16.024	5.800	2.000	0.000	0.000	19.000
11	1.082	-14.434	0.000	0.000	0.000	16.119	0.000
12	1.057	-15.302	11.200	7.500	0.000	0.000	0.000
13	1.071	-15.302	0.000	0.000	0.000	10.423	0.000
14	1.042	-16.191	6.200	1.600	0.000	0.000	0.000
15	1.038	-16.278	8.200	2.500	0.000	0.000	0.000
16	1.045	-15.880	3.500	1.800	0.000	0.000	0.000
17	1.039	-16.188	9.000	5.800	0.000	0.000	0.000
18	1.028	-16.884	3.200	0.900	0.000	0.000	0.000
19	1.025	-17.052	9.500	3.400	0.000	0.000	0.000
20	1.029	-16.852	2.200	0.700	0.000	0.000	0.000
21	1.032	-16.468	17.500	11.200	0.000	0.000	0.000
22	1.033	-16.455	0.000	0.000	0.000	0.000	0.000
23	1.027	-16.662	3.200	1.600	0.000	0.000	0.000
24	1.022	-16.830	8.700	6.700	0.000	0.000	4.300
25	1.019	-16.424	0.000	0.000	0.000	0.000	0.000
26	1.001	-16.842	3.500	2.300	0.000	0.000	0.000
27	1.026	-15.912	0.000	0.000	0.000	0.000	0.000
28	1.011	-12.057	0.000	0.000	0.000	0.000	0.000
29	1.006	-17.136	2.400	0.900	0.000	0.000	0.000
30	0.995	-18.015	10.600	1.900	0.000	0.000	0.000
Total			283.400	126.200	300.998	125.144	23.300

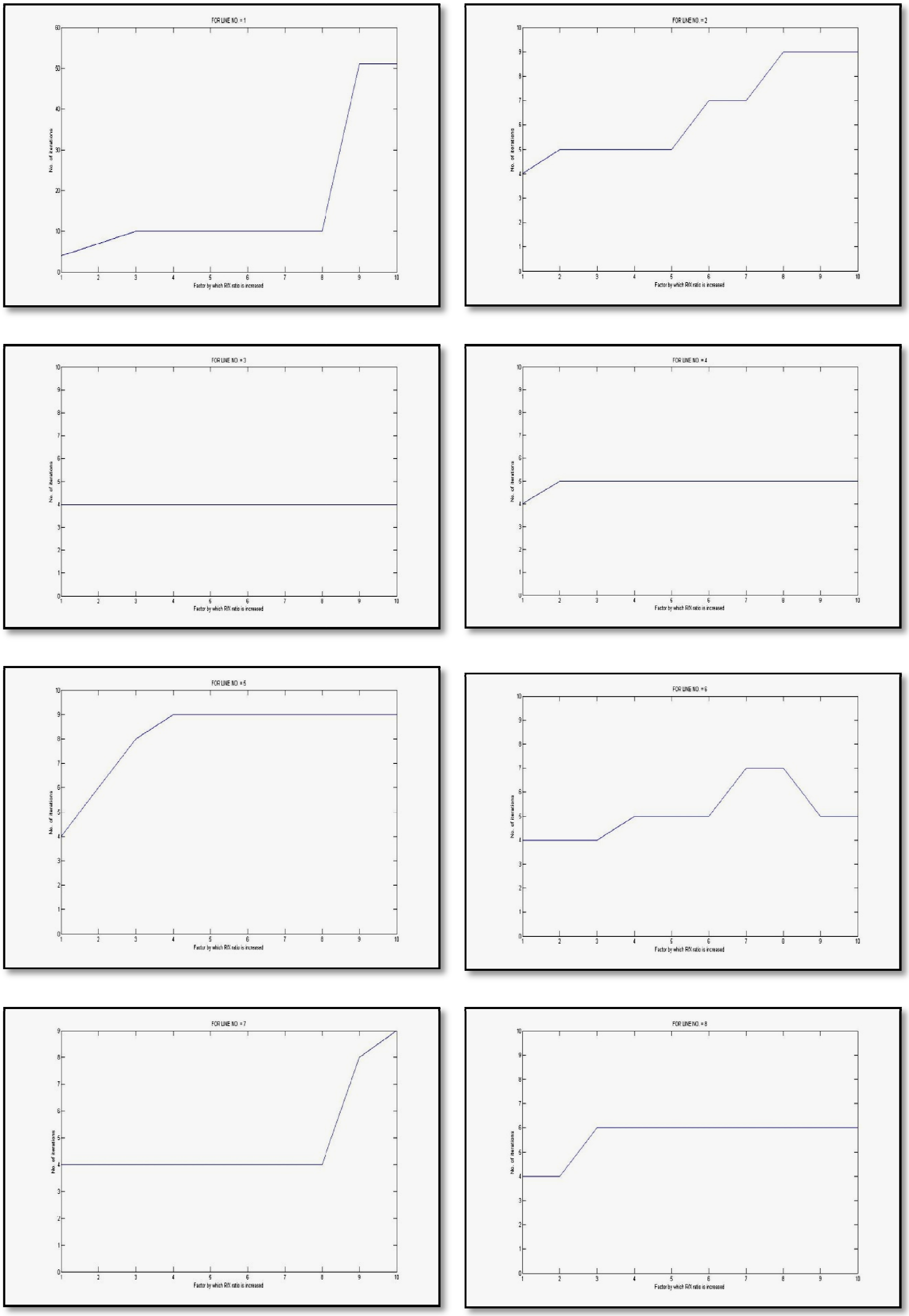
TABLE-6.1: No. of iterations while changing the R/X ratio of individual lines

LINE NO.	r=1	2	3	4	5	6	7	8	9	10
1	4	7	10	10	10	10	10	10	NC	NC
2	4	5	5	5	5	7	7	9	9	9
3	4	4	4	4	4	4	4	4	4	4
4	4	5	5	5	5	5	5	5	5	5
5	4	6	8	9	9	9	9	9	9	9
6	4	4	4	5	5	5	7	7	5	5
7	4	4	4	4	4	4	4	4	8	9
8	4	4	6	6	6	6	6	6	6	6
9	4	6	6	6	7	7	8	8	8	8
10	4	4	4	4	4	4	4	4	4	4
11	4	4	4	4	4	4	4	4	4	4
12	4	4	4	4	4	4	4	4	4	4
13	4	4	4	4	4	4	4	4	4	4
14	4	4	4	4	4	4	4	4	4	4
15	4	4	4	4	4	4	4	4	4	4
16	4	4	4	4	4	4	4	4	4	4
17	4	4	4	4	4	4	4	4	4	4
18	4	4	4	4	4	4	4	4	4	4
19	4	4	4	4	4	4	4	4	4	4
20	4	4	4	4	4	4	4	4	4	4
21	4	4	4	4	4	4	4	4	4	4
22	4	4	4	4	4	4	4	4	4	4
23	4	4	4	4	4	4	4	4	4	4
24	4	4	4	4	4	4	4	4	4	4
25	4	4	4	4	4	4	4	4	4	4
26	4	4	4	4	4	4	4	4	4	4
27	4	4	4	4	4	4	4	4	4	4
28	4	4	4	4	4	4	4	4	4	4
29	4	4	4	4	4	4	4	4	4	4
30	4	4	4	4	4	4	4	4	4	4
31	4	4	4	4	4	4	4	4	4	4
32	4	4	4	4	4	4	4	4	4	4
33	4	4	4	4	4	4	4	4	4	4
34	4	4	4	4	4	4	4	4	4	4
35	4	4	4	4	4	4	4	4	4	4
36	4	4	4	4	4	4	4	4	4	4
37	4	4	4	4	4	4	4	4	4	4
38	4	4	4	4	4	4	4	4	4	4
39	4	4	4	4	4	4	4	4	4	4
40	4	4	4	4	4	4	4	4	4	4
41	4	4	4	4	4	4	4	4	4	4

TABLE-6.2: No. of iterations while changing the R/X ratio of five lines at once

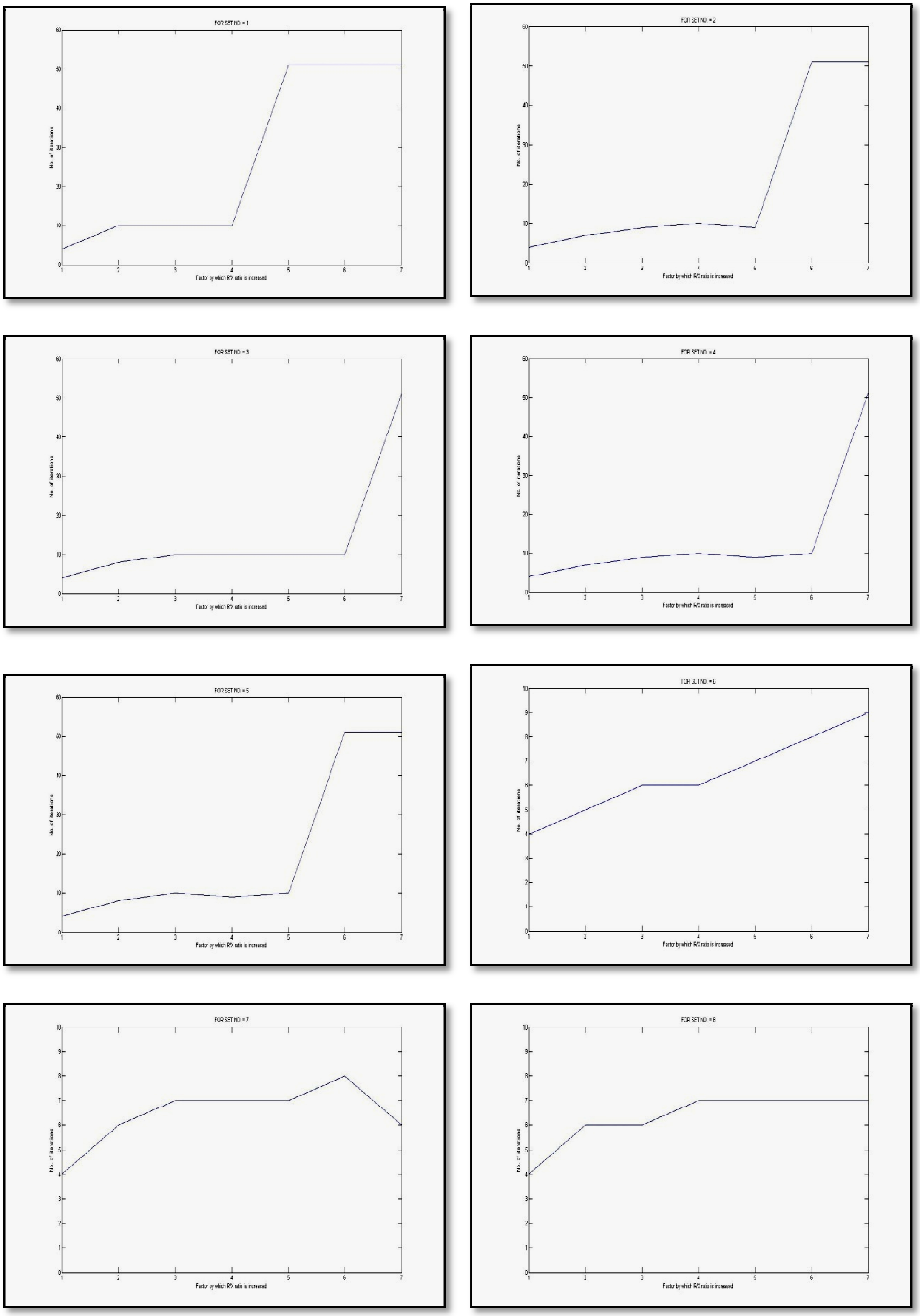
SET NO.	r=1	2	3	4	5	6	7
1	4	10	10	10	NC	NC	NC
2	4	7	9	10	9	NC	NC
3	4	8	10	10	10	10	NC
4	4	7	9	10	9	10	NC
5	4	8	10	9	10	NC	NC
6	4	5	6	6	7	8	9
7	4	6	7	7	7	8	6
8	4	6	6	7	7	7	7
9	4	4	7	5	7	7	7
10	4	4	4	4	4	4	4
11	4	4	4	4	4	4	4
12	4	4	4	4	4	4	4
13	4	4	4	4	4	4	4
14	4	4	4	4	4	4	4
15	4	4	4	4	4	4	4
16	4	4	4	4	4	4	4
17	4	4	4	4	4	4	4
18	4	4	4	4	4	4	4
19	4	4	4	4	4	4	4
20	4	4	4	4	4	4	4
21	4	4	4	4	4	4	4
22	4	4	4	4	4	4	4
23	4	4	4	4	4	4	4
24	4	4	4	4	4	4	4
25	4	4	4	4	4	4	4
26	4	4	4	4	4	4	4
27	4	4	4	4	4	4	4
28	4	4	4	4	4	4	4
29	4	4	4	4	4	4	4
30	4	4	4	4	4	4	4
31	4	4	4	4	4	4	4
32	4	4	4	4	4	4	4
33	4	4	4	4	4	4	4
34	4	4	4	4	4	4	4
35	4	4	4	4	4	4	4
36	4	4	4	4	4	4	4
37	4	4	4	4	4	4	4

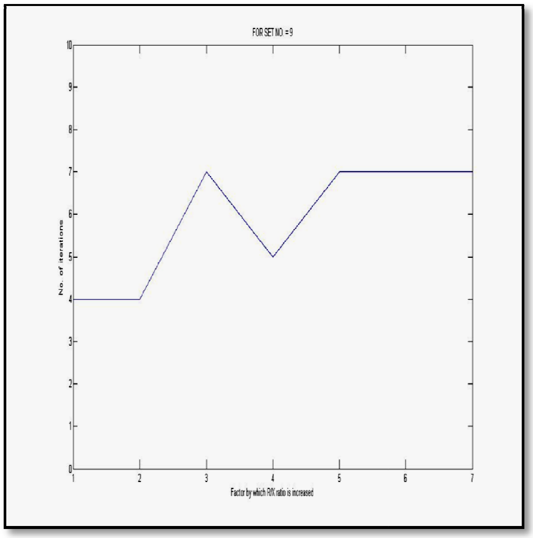
(a) Fig.6.1: No. of iterations vs R/X ratio for individual lines

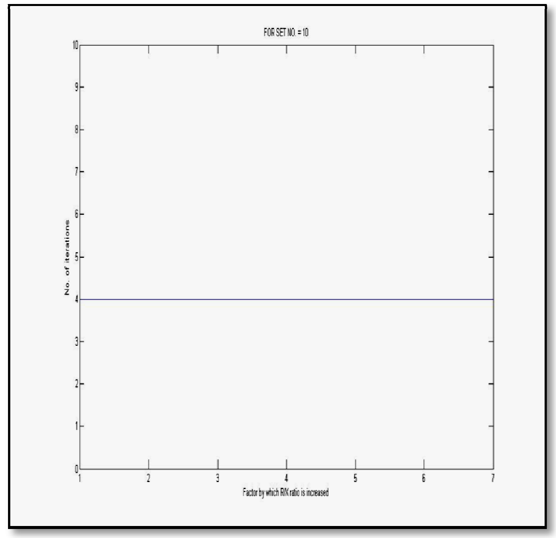


The plots for the other lines (lines 10 to 41) are similar to that of line 3.

(b) Fig.6.2: No. of iterations vs R/X ratio for sets of 5 lines







The plots for the other sets (set 11 to 37) are same as that of set 10.

The graphs shown above represent the data from Tables-6.1, 6.2 in pictorial form.

By changing the R/X ratio of each line separately and checking the number of iterations required for the system to converge, we see that the number of iterations increase as we increase the R/X ratio and in some cases the system becomes entirely unstable and is unable to converge. This has been represented by the symbol ‘NC’ in the above table. Under such situations, the MATLAB program loop runs indefinitely unless limited by a given value of maximum number of iterations. From the above table we also see that the contribution of each line towards the stability of the system may not be the same. The system stability depends more on the lines which show a significant rise in the number of iterations required when their R/X ratio is changed.

Changing the R/X ratio of five lines at once produces a more significant change in the number of iterations required. In this case also we see that some group of lines have more effect on the system stability compared to the others.

2) DISTRIBUTION SYSTEM

FOR 13-NODE TEST FEEDER SYSTEM:

Newton-Raphson load flow solution for the IEEE 13 Node Test Feeder system using the MATLAB program:

Power Flow Solution by Newton-Raphson Method

Maximum Power Mismatch = 1.697e-005

No. of Iterations = 4

Bus	Voltage	Angle	------Load------		---Generation---		Injected
No.	Mag.	Degree	MW	Mvar	MW	Mvar	Mvar
1	1.000	0.000	0.000	0.000	1.849	-10.436	1.000
2	1.037	-1.266	0.230	0.132	0.000	0.000	1.000
3	1.036	-1.222	0.170	0.125	0.000	0.000	1.000
4	1.035	-1.077	0.000	0.000	0.000	0.000	1.000
5	1.036	-1.120	0.133	0.097	0.000	0.000	1.000
6	1.059	-1.903	0.170	0.080	0.000	0.000	1.000
7	1.058	-1.861	0.000	0.000	0.000	0.000	1.000
8	1.057	-1.740	0.385	0.220	0.000	0.000	1.000
9	1.057	-1.791	0.170	0.151	0.000	0.000	1.000
10	1.057	-1.830	0.281	0.154	0.000	0.000	1.000
11	1.059	-1.961	0.128	0.086	0.000	0.000	1.000
12	1.058	-1.774	0.000	0.000	0.000	0.000	1.000
Total			1.667	1.045	1.849	-10.436	12.000

TABLE-6.3: Maximum power mismatch while changing the R/X of individual lines

LINE NO. ->	1	2	3	4	5
r=1	1.70e-05	1.70e-05	1.70e-05	1.70e-05	1.70e-05
2	1.65e-05	1.70e-05	1.70e-05	1.92e-05	1.69e-05
3	1.61e-05	1.68e-05	1.70e-05	2.34e-05	1.69e-05
4	1.60e-05	1.67e-05	1.70e-05	2.92e-05	1.69e-05
5	1.60e-05	1.66e-05	1.70e-05	3.64e-05	1.68e-05
6	1.60e-05	1.65e-05	1.70e-05	4.52e-05	1.68e-05
7	1.60e-05	1.64e-05	1.70e-05	5.56e-05	1.68e-05
8	1.61e-05	1.64e-05	1.69e-05	6.78e-05	1.67e-05
9	1.62e-05	1.64e-05	1.69e-05	8.20e-05	1.67e-05
10	1.63e-05	1.64e-05	1.69e-05	9.84e-05	1.66e-05
11	1.64e-05	1.64e-05	1.69e-05	0.000117	1.66e-05
12	1.65e-05	1.64e-05	1.69e-05	0.000138	1.66e-05
13	1.66e-05	1.64e-05	1.69e-05	0.000162	1.65e-05
14	1.67e-05	1.64e-05	1.69e-05	0.000189	1.65e-05
15	1.68e-05	1.64e-05	1.69e-05	0.000219	1.65e-05
16	1.69e-05	1.64e-05	1.69e-05	0.000252	1.64e-05
17	1.70e-05	1.64e-05	1.69e-05	0.000288	1.64e-05
18	1.71e-05	1.64e-05	1.69e-05	0.000327	1.63e-05
19	1.72e-05	1.64e-05	1.69e-05	0.000371	1.63e-05
20	1.73e-05	1.65e-05	1.69e-05	0.000418	1.63e-05

LINE NO. ->	6	7	8, 9	10	11
r=1	1.70e-05	1.70e-05	1.70e-05	1.70e-05	1.70e-05
2	2.25e-05	1.68e-05	1.70e-05	1.70e-05	1.69e-05
3	2.59e-05	1.76e-05	1.69e-05	1.69e-05	1.69e-05
4	2.82e-05	1.84e-05	1.69e-05	1.69e-05	1.69e-05
5	3.01e-05	1.88e-05	1.69e-05	1.69e-05	1.68e-05
6	3.20e-05	1.91e-05	1.69e-05	1.69e-05	1.68e-05
7	3.39e-05	1.93e-05	1.69e-05	1.69e-05	1.68e-05
8	3.65e-05	1.95e-05	1.69e-05	1.69e-05	1.67e-05
9	4.20e-05	1.97e-05	1.69e-05	1.69e-05	1.67e-05
10	4.77e-05	1.99e-05	1.68e-05	1.69e-05	1.67e-05
11	5.37e-05	2.01e-05	1.68e-05	1.68e-05	1.66e-05
12	5.99e-05	2.03e-05	1.68e-05	1.68e-05	1.66e-05
13	6.66e-05	2.05e-05	1.68e-05	1.68e-05	1.66e-05
14	7.35e-05	2.07e-05	1.68e-05	1.68e-05	1.65e-05
15	8.09e-05	2.09e-05	1.68e-05	1.68e-05	1.65e-05
16	8.88e-05	2.12e-05	1.68e-05	1.68e-05	1.65e-05
17	9.71e-05	2.14e-05	1.67e-05	1.68e-05	1.64e-05
18	0.000106	2.16e-05	1.67e-05	1.68e-05	1.64e-05
19	0.000115	2.19e-05	1.67e-05	1.67e-05	1.64e-05
20	0.000125	2.22e-05	1.67e-05	1.67e-05	1.63e-05

The R/X ratio is changed in a manner similar to that in transmission system. The data in Table-6.3 shows the maximum power mismatch in the 13-node system when the R/X ratio is changed for each line individually. In the above distribution system though there is no significant rise in the number of iterations required for convergence, the maximum power mismatch varies over a wide range.

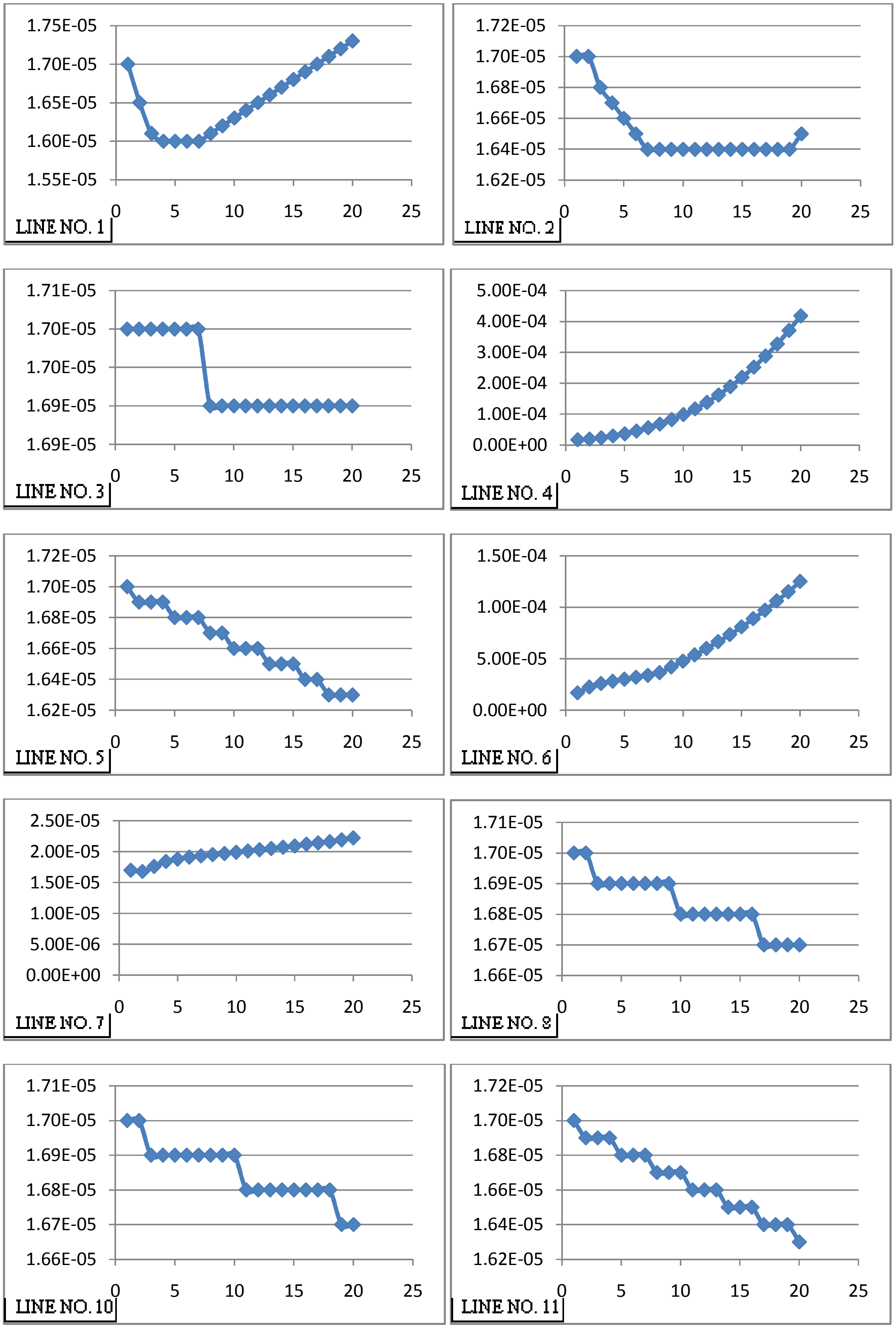
TABLE-6.4: Maximum power mismatch while changing the R/X of five lines at once

SET NO.->	1	2	3	4	5	6	7
r=1	1.70e-05	1.70e-05	1.70e-05	1.70e-05	1.70e-05	1.70e-05	1.70e-05
2	1.87e-05	2.50e-05	2.49e-05	2.49e-05	2.24e-05	2.24e-05	1.91e-05
3	2.22e-05	3.32e-05	3.34e-05	3.34e-05	2.57e-05	2.57e-05	2.23e-05
4	2.76e-05	4.27e-05	4.33e-05	4.33e-05	2.80e-05	2.81e-05	2.41e-05
5	3.45e-05	5.41e-05	5.53e-05	5.53e-05	3.00e-05	3.01e-05	2.51e-05
6	4.33e-05	6.84e-05	7.02e-05	7.03e-05	3.20e-05	3.20e-05	2.59e-05
7	5.40e-05	8.62e-05	8.88e-05	8.89e-05	3.39e-05	3.39e-05	2.65e-05
8	6.69e-05	0.000108	0.000112	0.000112	3.58e-05	3.58e-05	2.70e-05
9	8.24e-05	0.000136	0.00014	0.00014	3.78e-05	3.78e-05	2.74e-05
10	0.000101	0.00017	0.000175	0.000175	4.35e-05	4.31e-05	2.79e-05
11	0.000122	0.000211	0.000216	0.000217	4.99e-05	4.94e-05	2.82e-05
12	0.000147	0.00026	0.000266	0.000266	5.69e-05	5.61e-05	2.86e-05
13	0.000175	0.000318	0.000324	0.000325	6.45e-05	6.36e-05	2.90e-05
14	0.000208	0.000387	0.000392	0.000394	7.29e-05	7.17e-05	2.94e-05
15	0.000245	0.000467	0.000471	0.000473	8.21e-05	8.06e-05	2.98e-05
16	0.000287	0.00056	0.000562	0.000564	9.23e-05	9.04e-05	3.02e-05
17	0.000334	0.000667	0.000667	0.00067	0.000103	0.000101	3.06e-05
18	0.000386	0.000811	0.000891	0.000895	0.000116	0.000113	3.10e-05
19	0.000445	3.92e-05	5.58e-05	5.69e-05	0.000129	0.000126	3.14e-05
20	0.00051	7.49e-05	0.000109	0.000112	0.000144	0.000141	3.18e-05

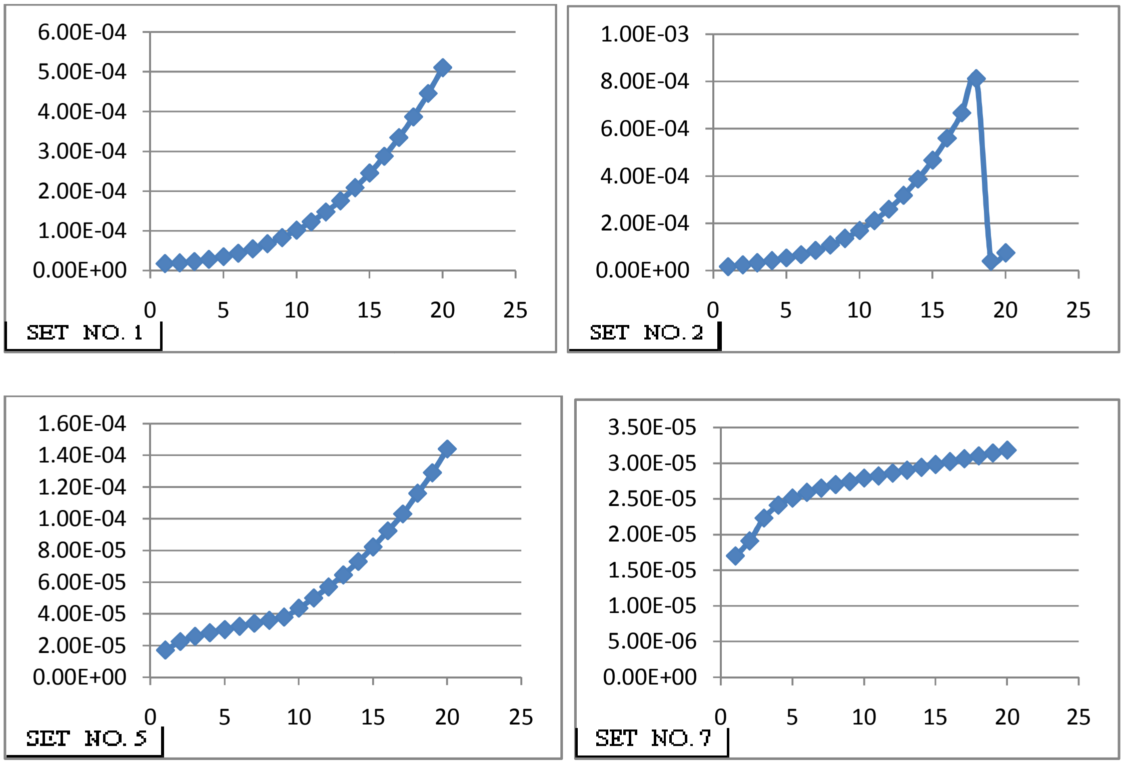
The R/X ratio was changed for 5 lines at once in order to show the wide variation in the values of maximum power mismatch.

Hence, increase in the R/X ratio for a transmission system generally increases the number of iterations required for convergence and results in non-convergence of the system in some cases. In this case of distribution system, increase in R/X ratio generally increases the maximum power mismatch in the system over a wide range of values.

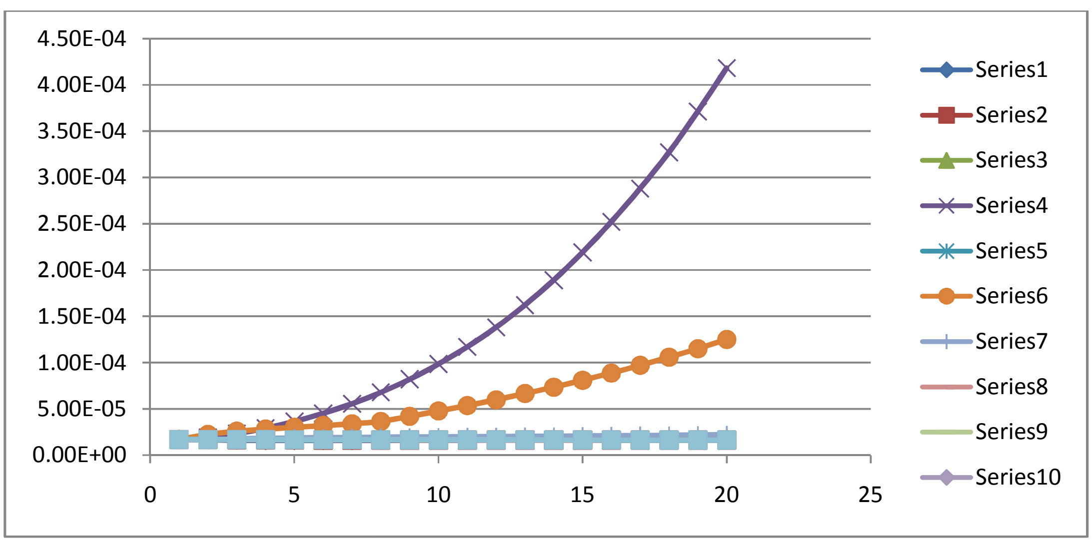
(a) Fig.6.3: Maximum power mismatch vs R/X for individual lines



(b) Fig.6.4: Maximum power mismatch vs R/X for sets of 5 lines



(c) Fig.6.5 Comparison of power mismatches vs R/X ratio of all lines



The above graph shows that the R/X ratio of the LINE NO. 4 can highly affect the convergence of the NR method as it has a large increase in maximum power mismatch with respect to the increase in the ratio.

FOR 38-NODE TEST FEEDER SYSTEM:

Newton-Raphson load flow solution for the IEEE 38 Node Test Feeder system using the MATLAB program:

Power Flow Solution by Newton-Raphson Method
Maximum Power Mismatch = 7.8527e-006
No. of Iterations = 2

Bus No.	Voltage Mag.	Angle Degree	------Load------ MW	Mvar	---Generation--- MW	Mvar	Injected Mvar
1	1.000	0.000	0.000	0.000	3.715	2.300	0.000
2	1.000	0.000	0.100	0.060	0.000	0.000	0.000
3	1.000	0.001	0.090	0.040	0.000	0.000	0.000
4	1.000	0.001	0.120	0.080	0.000	0.000	0.000
5	1.000	0.002	0.060	0.030	0.000	0.000	0.000
6	1.000	0.001	0.060	0.020	0.000	0.000	0.000
7	0.999	-0.001	0.200	0.100	0.000	0.000	0.000
8	0.999	-0.001	0.200	0.100	0.000	0.000	0.000
9	0.999	-0.001	0.060	0.020	0.000	0.000	0.000
10	0.999	-0.002	0.060	0.020	0.000	0.000	0.000
11	0.999	-0.002	0.045	0.030	0.000	0.000	0.000
12	0.999	-0.002	0.060	0.035	0.000	0.000	0.000
13	0.999	-0.002	0.060	0.035	0.000	0.000	0.000
14	0.999	-0.003	0.120	0.080	0.000	0.000	0.000
15	0.999	-0.003	0.060	0.010	0.000	0.000	0.000
16	0.999	-0.004	0.060	0.020	0.000	0.000	0.000
17	0.999	-0.004	0.060	0.020	0.000	0.000	0.000
18	0.999	-0.004	0.090	0.040	0.000	0.000	0.000
19	1.000	0.000	0.090	0.040	0.000	0.000	0.000
20	1.000	-0.001	0.090	0.040	0.000	0.000	0.000
21	1.000	-0.001	0.090	0.040	0.000	0.000	0.000
22	1.000	-0.001	0.090	0.040	0.000	0.000	0.000
23	1.000	0.001	0.090	0.050	0.000	0.000	0.000
24	1.000	-0.000	0.420	0.200	0.000	0.000	0.000
25	1.000	-0.001	0.420	0.200	0.000	0.000	0.000
26	1.000	0.002	0.060	0.025	0.000	0.000	0.000
27	0.999	0.002	0.060	0.025	0.000	0.000	0.000
28	0.999	0.003	0.060	0.020	0.000	0.000	0.000
29	0.999	0.003	0.120	0.070	0.000	0.000	0.000
30	0.999	0.004	0.200	0.600	0.000	0.000	0.000
31	0.999	0.004	0.150	0.070	0.000	0.000	0.000
32	0.999	0.003	0.210	0.100	0.000	0.000	0.000
33	0.999	0.003	0.060	0.040	0.000	0.000	0.000
34	0.999	-0.001	0.000	0.000	0.000	0.000	0.000
35	0.999	-0.001	0.000	0.000	0.000	0.000	0.000
36	0.999	-0.002	0.000	0.000	0.000	0.000	0.000
37	0.999	-0.004	0.000	0.000	0.000	0.000	0.000
38	1.000	-0.001	0.000	0.000	0.000	0.000	0.000
Total			3.715	2.300	3.715	2.300	0.000

TABLE-6.5: Maximum power mismatch while changing the R/X of individual lines

LINE NO:	1	2	3	4	5	6 –24,30-37
r=1	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06
2	8.09e-06	8.95e-06	8.41e-06	8.40e-06	9.00e-06	7.85e-06
3	8.32e-06	1.00e-05	8.97e-06	8.95e-06	1.01e-05	7.85e-06
4	8.55e-06	1.11e-05	9.53e-06	9.50e-06	1.13e-05	7.85e-06
5	8.79e-06	1.22e-05	1.01e-05	1.01e-05	1.24e-05	7.85e-06
6	9.02e-06	1.33e-05	1.06e-05	1.06e-05	1.36e-05	7.85e-06
7	9.25e-06	1.44e-05	1.12e-05	1.12e-05	1.47e-05	7.85e-06
8	9.49e-06	1.57e-05	1.18e-05	1.17e-05	1.59e-05	7.85e-06
9	9.72e-06	1.78e-05	1.23e-05	1.22e-05	1.70e-05	7.85e-06
10	9.95e-06	1.99e-05	1.29e-05	1.28e-05	1.82e-05	7.85e-06
11	1.02e-05	2.20e-05	1.34e-05	1.33e-05	1.93e-05	7.85e-06
12	1.04e-05	2.41e-05	1.40e-05	1.39e-05	2.05e-05	7.85e-06
13	1.07e-05	2.62e-05	1.45e-05	1.44e-05	2.18e-05	7.85e-06
14	1.09e-05	2.82e-05	1.51e-05	1.50e-05	2.34e-05	7.85e-06
15	1.11e-05	3.03e-05	1.57e-05	1.55e-05	2.50e-05	7.85e-06
16	1.14e-05	3.24e-05	1.62e-05	1.61e-05	2.66e-05	7.85e-06
17	1.16e-05	3.45e-05	1.68e-05	1.66e-05	2.81e-05	7.85e-06
18	1.18e-05	3.66e-05	1.73e-05	1.72e-05	2.97e-05	7.85e-06
19	1.21e-05	3.87e-05	1.79e-05	1.77e-05	3.13e-05	7.85e-06
20	1.23e-05	4.07e-05	1.84e-05	1.83e-05	3.28e-05	7.85e-06

LINE NO:	25	26	27	28	29	30
r=1	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06
2	7.98e-06	8.02e-06	8.43e-06	8.26e-06	9.52e-06	7.04e-06
3	8.11e-06	8.19e-06	9.01e-06	8.66e-06	1.02e-05	6.53e-06
4	8.23e-06	8.35e-06	9.59e-06	9.07e-06	1.05e-05	6.22e-06
5	8.36e-06	8.52e-06	1.02e-05	9.48e-06	1.08e-05	6.01e-06
6	8.49e-06	8.69e-06	1.07e-05	9.88e-06	1.11e-05	5.85e-06
7	8.62e-06	8.85e-06	1.13e-05	1.03e-05	1.13e-05	5.72e-06
8	8.74e-06	9.02e-06	1.19e-05	1.07e-05	1.14e-05	5.60e-06
9	8.87e-06	9.19e-06	1.25e-05	1.11e-05	1.16e-05	5.50e-06
10	9.00e-06	9.35e-06	1.31e-05	1.15e-05	1.18e-05	5.41e-06
11	9.13e-06	9.52e-06	1.36e-05	1.19e-05	1.19e-05	5.33e-06
12	9.25e-06	9.69e-06	1.42e-05	1.23e-05	1.21e-05	5.25e-06
13	9.38e-06	9.85e-06	1.48e-05	1.27e-05	1.22e-05	5.19e-06
14	9.51e-06	1.00e-05	1.54e-05	1.31e-05	1.24e-05	5.19e-06
15	9.64e-06	1.02e-05	1.59e-05	1.35e-05	1.25e-05	5.19e-06
16	9.76e-06	1.04e-05	1.65e-05	1.39e-05	1.27e-05	5.19e-06
17	9.89e-06	1.05e-05	1.71e-05	1.43e-05	1.28e-05	5.19e-06
18	1.00e-05	1.07e-05	1.77e-05	1.47e-05	1.30e-05	5.19e-06
19	1.01e-05	1.09e-05	1.82e-05	1.52e-05	1.31e-05	5.19e-06
20	1.03e-05	1.10e-05	1.88e-05	1.56e-05	1.33e-05	5.19e-06

TABLE-6.6: Maximum power mismatch while changing the R/X of ten lines at once

SET NO:	1	2	3	4	5	6-13	14
r=1	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06
2	1.14e-05	1.12e-05	1.01e-05	9.55e-06	9.00e-06	7.85e-06	7.85e-06
3	1.50e-05	1.46e-05	1.24e-05	1.12e-05	1.01e-05	7.85e-06	7.85e-06
4	1.86e-05	1.79e-05	1.46e-05	1.29e-05	1.13e-05	7.85e-06	7.85e-06
5	2.22e-05	2.12e-05	1.69e-05	1.46e-05	1.24e-05	7.85e-06	7.85e-06
6	2.58e-05	2.46e-05	1.91e-05	1.63e-05	1.36e-05	7.85e-06	7.85e-06
7	2.93e-05	2.79e-05	2.14e-05	1.80e-05	1.47e-05	7.85e-06	7.85e-06
8	3.29e-05	3.13e-05	2.36e-05	1.97e-05	1.59e-05	7.85e-06	7.85e-06
9	3.65e-05	3.46e-05	2.59e-05	2.14e-05	1.70e-05	7.85e-06	7.85e-06
10	4.01e-05	3.80e-05	2.81e-05	2.31e-05	1.82e-05	7.85e-06	7.85e-06
11	4.36e-05	4.13e-05	3.04e-05	2.48e-05	1.93e-05	7.85e-06	7.85e-06
12	4.72e-05	4.46e-05	3.26e-05	2.65e-05	2.05e-05	7.85e-06	7.85e-06
13	5.08e-05	4.80e-05	3.49e-05	2.82e-05	2.18e-05	7.85e-06	7.85e-06
14	5.44e-05	5.13e-05	3.71e-05	2.99e-05	2.34e-05	7.85e-06	7.85e-06
15	5.79e-05	5.47e-05	3.94e-05	3.16e-05	2.50e-05	7.85e-06	7.85e-06
16	6.15e-05	5.80e-05	4.16e-05	3.39e-05	2.66e-05	7.85e-06	7.85e-06
17	6.51e-05	6.13e-05	4.39e-05	3.62e-05	2.81e-05	7.85e-06	7.85e-06
18	6.86e-05	6.47e-05	4.61e-05	3.85e-05	2.97e-05	7.85e-06	7.85e-06
19	7.22e-05	6.80e-05	4.84e-05	4.08e-05	3.13e-05	7.85e-06	7.85e-06
20	7.58e-05	7.13e-05	5.06e-05	4.31e-05	3.28e-05	7.85e-06	8.09e-06

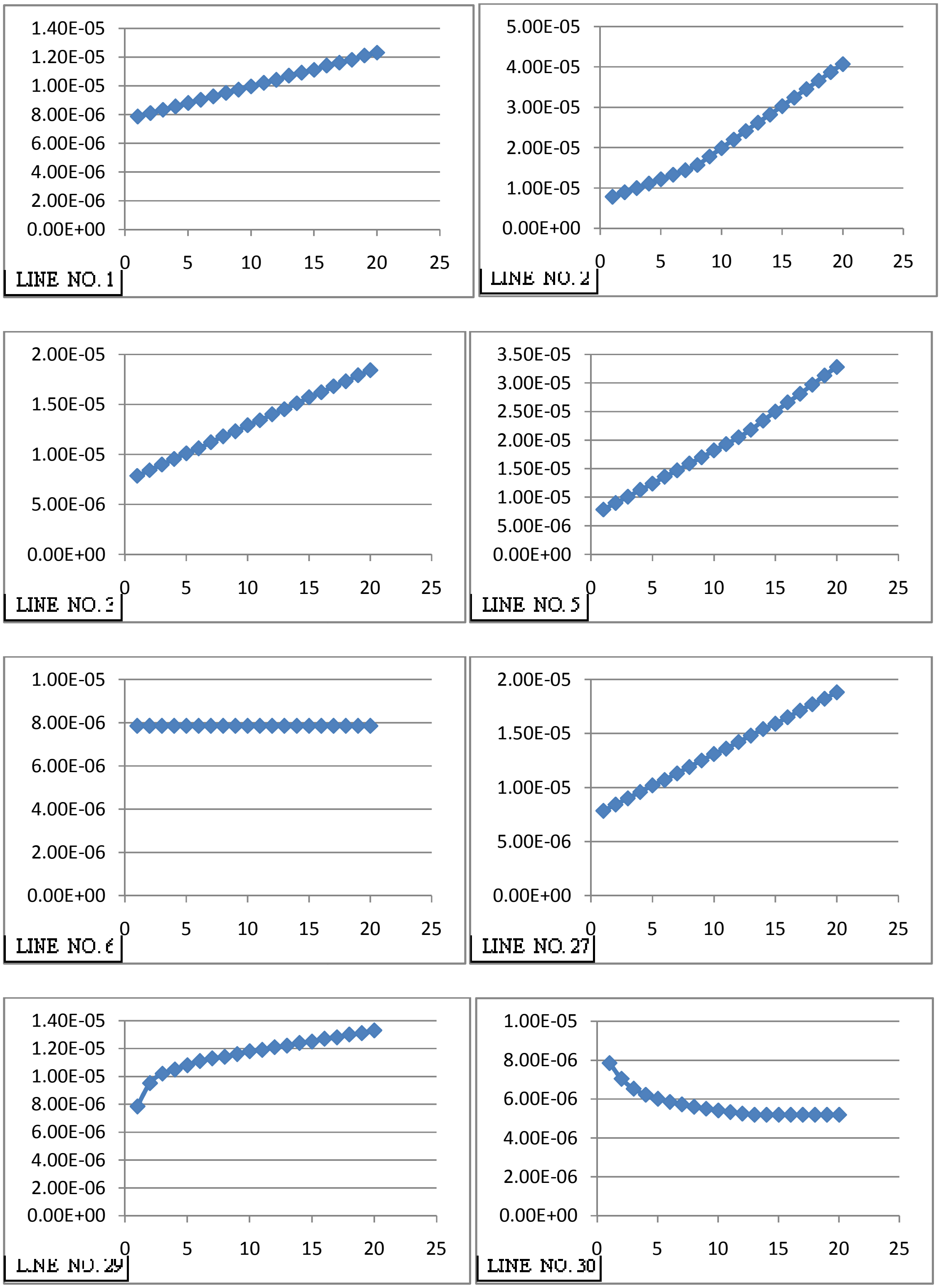
SET NO:	15	16	17	18	19	20	21
r=1	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06
2	7.85e-06	7.98e-06	8.15e-06	8.72e-06	9.13e-06	1.11e-05	1.01e-05
3	7.85e-06	8.11e-06	8.44e-06	9.60e-06	1.04e-05	1.34e-05	1.16e-05
4	7.85e-06	8.23e-06	8.73e-06	1.05e-05	1.17e-05	1.55e-05	1.31e-05
5	7.85e-06	8.36e-06	9.03e-06	1.13e-05	1.30e-05	1.75e-05	1.45e-05
6	7.85e-06	8.49e-06	9.32e-06	1.22e-05	1.42e-05	1.95e-05	1.59e-05
7	7.85e-06	8.62e-06	9.62e-06	1.31e-05	1.55e-05	2.15e-05	1.73e-05
8	7.85e-06	8.74e-06	9.91e-06	1.40e-05	1.68e-05	2.34e-05	1.87e-05
9	7.85e-06	8.87e-06	1.02e-05	1.48e-05	1.81e-05	2.54e-05	2.01e-05
10	7.85e-06	9.00e-06	1.05e-05	1.57e-05	1.93e-05	2.73e-05	2.15e-05
11	7.85e-06	9.13e-06	1.08e-05	1.66e-05	2.06e-05	2.92e-05	2.30e-05
12	7.85e-06	9.25e-06	1.11e-05	1.74e-05	2.19e-05	3.11e-05	2.44e-05
13	7.85e-06	9.38e-06	1.14e-05	1.83e-05	2.32e-05	3.30e-05	2.58e-05
14	7.85e-06	9.51e-06	1.17e-05	1.92e-05	2.45e-05	3.50e-05	2.72e-05
15	7.85e-06	9.64e-06	1.20e-05	2.01e-05	2.57e-05	3.69e-05	2.86e-05
16	7.85e-06	9.76e-06	1.23e-05	2.09e-05	2.70e-05	3.88e-05	3.00e-05
17	7.85e-06	9.89e-06	1.26e-05	2.18e-05	2.83e-05	4.07e-05	3.15e-05
18	8.17e-06	1.00e-05	1.29e-05	2.27e-05	2.96e-05	4.26e-05	3.29e-05
19	8.58e-06	1.01e-05	1.31e-05	2.35e-05	3.08e-05	4.45e-05	3.43e-05
20	9.00e-06	1.03e-05	1.34e-05	2.44e-05	3.21e-05	4.64e-05	3.57e-05

SET NO:	22	23	24	25	26	27	28
r=1	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06	7.85e-06
2	1.01e-05	1.01e-05	1.01e-05	1.01e-05	9.96e-06	9.78e-06	9.14e-06
3	1.16e-05	1.16e-05	1.16e-05	1.16e-05	1.13e-05	1.10e-05	9.69e-06
4	1.31e-05	1.31e-05	1.31e-05	1.31e-05	1.26e-05	1.21e-05	1.02e-05
5	1.45e-05	1.45e-05	1.45e-05	1.45e-05	1.39e-05	1.32e-05	1.06e-05
6	1.59e-05	1.59e-05	1.59e-05	1.59e-05	1.52e-05	1.43e-05	1.11e-05
7	1.73e-05	1.73e-05	1.73e-05	1.73e-05	1.65e-05	1.53e-05	1.15e-05
8	1.87e-05	1.87e-05	1.87e-05	1.87e-05	1.77e-05	1.64e-05	1.20e-05
9	2.01e-05	2.01e-05	2.01e-05	2.01e-05	1.90e-05	1.75e-05	1.24e-05
10	2.15e-05	2.15e-05	2.15e-05	2.15e-05	2.03e-05	1.86e-05	1.29e-05
11	2.30e-05	2.30e-05	2.30e-05	2.30e-05	2.16e-05	1.97e-05	1.34e-05
12	2.44e-05	2.44e-05	2.44e-05	2.44e-05	2.28e-05	2.08e-05	1.38e-05
13	2.58e-05	2.58e-05	2.58e-05	2.58e-05	2.41e-05	2.19e-05	1.43e-05
14	2.72e-05	2.72e-05	2.72e-05	2.72e-05	2.54e-05	2.30e-05	1.47e-05
15	2.86e-05	2.86e-05	2.86e-05	2.86e-05	2.67e-05	2.41e-05	1.52e-05
16	3.00e-05	3.00e-05	3.00e-05	3.00e-05	2.79e-05	2.52e-05	1.57e-05
17	3.15e-05	3.15e-05	3.15e-05	3.15e-05	2.92e-05	2.63e-05	1.61e-05
18	3.29e-05	3.29e-05	3.29e-05	3.29e-05	3.05e-05	2.74e-05	1.66e-05
19	3.43e-05	3.43e-05	3.43e-05	3.43e-05	3.18e-05	2.85e-05	1.71e-05
20	3.57e-05	3.57e-05	3.57e-05	3.57e-05	3.31e-05	2.96e-05	1.75e-05

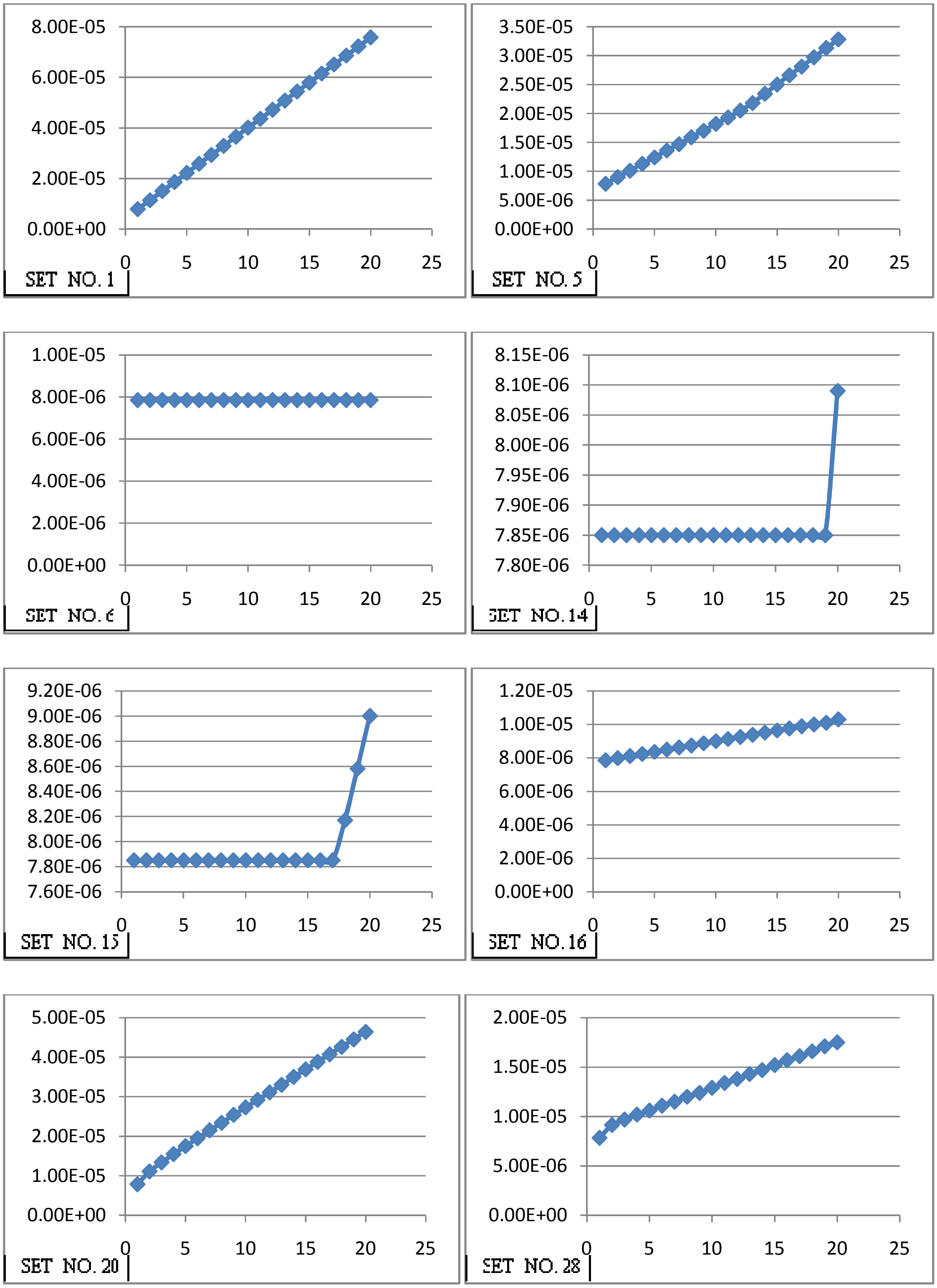
For the 38-node test feeder system, the R/X ratio was changed in a manner similar to the previous cases of 30-node transmission system and 13-node distribution system. From the above data it is seen that it also follows the same trend of increasing power mismatch with increase in R/X ratio. The number of iterations required for convergence of the system increases slightly from 2 to 4 iterations with the R/X ratio changed by upto 20 times.

Hence, the main difficulty faced while applying the Newton-Raphson method to distribution systems is that the maximum power mismatch increases with increase in R/X ratio of the lines and may show a sharp rise for changes in R/X ratio of certain lines in the system. In case of the 38-node system, line 2 and line 5 are two such lines.

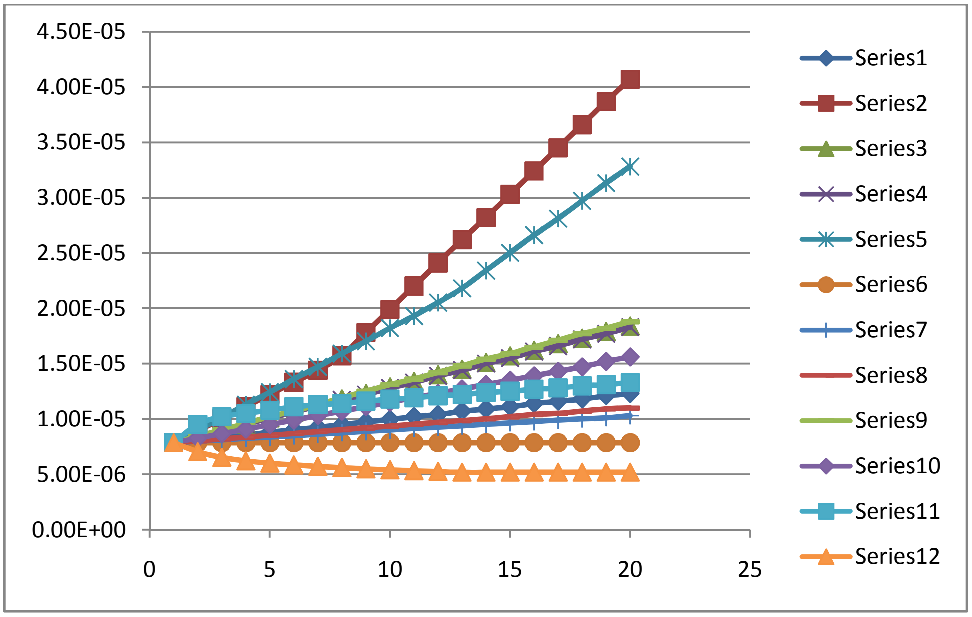
(a) Fig.6.6: Maximum power mismatch vs R/X for individual lines



(b) Fig.6.7: Maximum power mismatch vs R/X for sets of ten lines



(c) Fig.6.8: Comparison of power mismatches vs R/X ratio of all lines



In the graph shown above it is clear that the convergence of the NR method is mostly affected by the R/X ratio of the LINE NO. 2 and LINE NO. 5 of the distribution system.

The above graph shows the characteristics of a typical distribution system. The maximum power mismatch versus the R/X ratio curve generally shows an increasing trend. As shown in the plot above, change in the R/X ratio of some lines in the system can have more effect on the system stability while some others produce negligible effect on the system stability.

CHAPTER VII: CONCLUSION

Though the Newton-Raphson method has found wide applications in the field of power systems, it does not perform satisfactorily for systems with high R/X ratios. The application of the Newton-Raphson method in such situations either results in drastic increase of the number of iterations required for the system to converge or the maximum power mismatch of the system increases.

For transmission systems, the increase in the R/X ratio causes huge increase in the number of iterations required for relatively small changes in the resistance of the lines, sometimes the system starts diverging after a particular value of the R/X ratio is reached.

For distribution systems, the increase in the R/X ratio increases the level of maximum power mismatch over a wide range of values. The number of iterations required for convergence also increases but it is not as pronounced as that in case of transmission system.

Hence, it can be said that the application of the Newton-Raphson method is mostly limited to strongly meshed systems with low R/X ratio closer of 0.5.

In the Indian power system scenario this poses a great problem because of the radial system of the distribution systems in prevalence and the increase in the number of distributed sources of power generation over the years.

REFERENCES

[1] B. Venkatesh, A. Dukpa, and L. Chang, “An accurate voltage solution method for radial distribution systems”, Can. J. Elect. Comput. Eng., Vol. 34, No. 1/2, 2009

[2] Saadat H., Power System Analysis, Tata McGraw-Hill, New Delhi, 1999, 2002 edition.

[3] Wadhwa C.L., Electrical Power Systems, New Age, New Delhi, 1983, 6th edition.

[4] Tinney W. F., and Hart C. E, 'Power flow solution by Newton's method', IEEE Trans., 1967, Pas-86, pp. 1449-1456

[5] B. Stott, “Effective starting process for Newton-Raphson load flows ” PROC. IEE, Vol. 118, No. 8, August 1971, pp. 983-987.

[6] Jianwei Liu, M. M. A. Salama and R. R. Mansour, “An efficient power flow algorithm for distribution systems with polynomial load”, International Journal of Electrical Engineering Education, 39/4, 2002, pp. 371-385.

[7] P.R. Bijwe and S.M. Kelapure, “Nondivergent Fast Power Flow Methods”, IEEE Trans. on Power Systems, Vol. 18, No. 2, May 2003, 633-638.

[8] W. H. Kersting, “A method to design and operation of a distribution system”, IEEE Trans. Power Apparatus and Systems, PAS-103, pp. 1945–1952, 1984.

[9] Biswarup Das, “Consideration of Input Parameter Uncertainties in Load Flow Solution of Three-Phase Unbalanced Radial Distribution System”, IEEE Transactions on Power Systems, Vol. 21, No. 3, August 2006.

[10] H. Shateri and S. Jamali, “Load Flow Method for Distribution Networks with Multiple Source Nodes”, IEEE Electrical Power & Energy Conference, 3/08, 2008.

Appendix

```
            IEEE 30-BUS TEST SYSTEM (American Electric Power)
            bus code =1(swing bus), 2(generator bus) and 3(load bus)
            Bus Bus  Voltage Angle   ---Load---- -------Generator----- Injected
            No  code Mag.    Degree  MW    Mvar  MW   Mvar Qmin Qmax    Mvar
busdata=[1   1    1.06   0.0     0.0   0.0    0    0.0   0    0        0
         2   2    1.043  0.0    21.70 12.7   40.0  0.0 -40   50        0
         3   0    1.0    0.0     2.4   1.2    0.0  0.0   0    0        0
         4   0    1.06   0.0     7.6   1.6    0.0  0.0   0    0        0
         5   2    1.01   0.0    94.2  19.0    0.0  0.0 -40   40        0
         6   0    1.0    0.0     0.0   0.0    0.0  0.0   0    0        0
         7   0    1.0    0.0    22.8  10.9    0.0  0.0   0    0        0
         8   2    1.01   0.0    30.0  30.0    0.0  0.0 -10   60        0
         9   0    1.0    0.0     0.0   0.0    0.0  0.0   0    0        0
        10   0    1.0    0.0     5.8   2.0    0.0  0.0  -6   24       19
        11   2    1.082  0.0     0.0   0.0    0.0  0.0   0    0        0
        12   0    1.0    0      11.2   7.5    0    0     0    0        0
        13   2    1.071  0       0     0.0    0    0    -6   24        0
        14   0    1      0       6.2   1.6    0    0     0    0        0
        15   0    1      0       8.2   2.5    0    0     0    0        0
        16   0    1      0       3.5   1.8    0    0     0    0        0
        17   0    1      0       9.0   5.8    0    0     0    0        0
        18   0    1      0       3.2   0.9    0    0     0    0        0
        19   0    1      0       9.5   3.4    0    0     0    0        0
        20   0    1      0       2.2   0.7    0    0     0    0        0
        21   0    1      0      17.5  11.2    0    0     0    0        0
        22   0    1      0       0     0.0    0    0     0    0        0
        23   0    1      0       3.2   1.6    0    0     0    0        0
        24   0    1      0       8.7   6.7    0    0     0    0      4.3
        25   0    1      0       0     0.0    0    0     0    0        0
        26   0    1      0       3.5   2.3    0    0     0    0        0
        27   0    1      0       0     0.0    0    0     0    0        0
        28   0    1      0       0     0.0    0    0     0    0        0
        29   0    1      0       2.4   0.9    0    0     0    0        0
        30   0    1      0      10.6   1.9    0    0     0    0        0];
```

```
                                                    Line code a
          Bus bus   R        X       1/2 B        = 1 for lines
          nl  nr    p.u.     p.u.     p.u.        > 1 or < 1 tr. tap at bus nl
linedata=[1   2   0.0192   0.0575   0.02640    1
          1   3   0.0452   0.1852   0.02040    1
          2   4   0.0570   0.1737   0.01840    1
          3   4   0.0132   0.0379   0.00420    1
          2   5   0.0472   0.1983   0.02090    1
          2   6   0.0581   0.1763   0.01870    1
          4   6   0.0119   0.0414   0.00450    1
          5   7   0.0460   0.1160   0.01020    1
          6   7   0.0267   0.0820   0.00850    1
          6   8   0.0120   0.0420   0.00450    1
          6   9   0.0      0.2080   0.0     0.978
          6  10   0         .5560   0       0.969
          9  11   0         .2080   0          1
          9  10   0         .1100   0          1
          4  12   0         .2560   0       0.932
         12  13   0         .1400   0          1
         12  14    .1231    .2559   0          1
         12  15    .0662    .1304   0          1
         12  16    .0945    .1987   0          1
         14  15    .2210    .1997   0          1
         16  17    .0824    .1923   0          1
         15  18    .1073    .2185   0          1
         18  19    .0639    .1292   0          1
         19  20    .0340    .0680   0          1
         10  20    .0936    .2090   0          1
         10  17    .0324    .0845   0          1
         10  21    .0348    .0749   0          1
         10  22    .0727    .1499   0          1
         21  22    .0116    .0236   0          1
         15  23    .1000    .2020   0          1
         22  24    .1150    .1790   0          1
         23  24    .1320    .2700   0          1
         24  25    .1885    .3292   0          1
         25  26    .2544    .3800   0          1
         25  27    .1093    .2087   0          1
         28  27     0       .3960   0       0.968
         27  29    .2198    .4153   0          1
         27  30    .3202    .6027   0          1
         29  30    .2399    .4533   0          1
          8  28    .0636    .2000   0.0214     1
          6  28    .0169    .0599   0.065      1];
```

IEEE 13-node test feeder data:

For 3 phase system:

Overhead Line Configuration Data:

Config.	Phasing	Phase	Neutral	Spacing
		ACSR	ACSR	ID
601	B A C N	556,500 26/7	4/0 6/1	500
602	C A B N	4/0 6/1	4/0 6/1	500
603	C B N	1/0	1/0	505
604	A C N	1/0	1/0	505
605	C N	1/0	1/0	510

Underground Line Configuration Data:

Config.	Phasing	Cable	Neutral	Space ID
606	A B C N	250,000 AA, CN	None	515
607	A N	1/0 AA, TS	1/0 Cu	520

Line Segment Data:

Node A	Node B	Length(ft.)	Config.
632	645	500	603
632	633	500	602
633	634	0	XFM-1
645	646	300	603
650	632	2000	601
684	652	800	607
632	671	2000	601
671	684	300	604
671	680	1000	601
671	692	0	Switch
684	611	300	605
692	675	500	606

Transformer Data:

	kVA	kV-high	kV-low	R - %	X - %
Substation:	5,000	115 - D	4.16 Gr. Y	1	8
XFM -1	500	4.16 – Gr.W	0.48 – Gr.W	1.1	2

Capacitor Data:

Node	Ph-A	Ph-B	Ph-C
	kVAr	kVAr	KVAr
675	200	200	200
611			100
Total	200	200	300

Regulator Data:

Regulator ID:	1		
Line Segment:	650 - 632		
Location:	50		
Phases:	A - B -C		
Connection:	3-Ph,LG		
Monitoring Phase:	A-B-C		
Bandwidth:	2.0 volts		
PT Ratio:	20		
Primary CT Rating:	700		
Compensator Settings:	Ph-A	Ph-B	Ph-C
R - Setting:	3	3	3
X - Setting:	9	9	9
Volltage Level:	122	122	122

Spot Load Data:

Node	Load	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3
	Model	kW	kVAr	kW	kVAr	kW	KVAr
634	Y-PQ	160	110	120	90	120	90
645	Y-PQ	0	0	170	125	0	0
646	D-Z	0	0	230	132	0	0
652	Y-Z	128	86	0	0	0	0
671	D-PQ	385	220	385	220	385	220
675	Y-PQ	485	190	68	60	290	212
692	D-I	0	0	0	0	170	151
611	Y-I	0	0	0	0	170	80
	TOTAL	1158	606	973	627	1135	753

Distributed Load Data:

Node A	Node B	Load	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3
		Model	kW	kVAr	kW	kVAr	kW	KVAr
632	671	Y-PQ	17	10	66	38	117	68

Impedances

Configuration 601:

Z (R +jX) in ohms per mile

0.3465 1.0179	0.1560 0.5017	0.1580 0.4236
	0.3375 1.0478	0.1535 0.3849
		0.3414 1.0348

B in micro Siemens per mile

6.2998	-1.9958	-1.2595
	5.9597	-0.7417
		5.6386

Configuration 602:

Z (R +jX) in ohms per mile

0.7526 1.1814	0.1580 0.4236	0.1560 0.5017
	0.7475 1.1983	0.1535 0.3849
		0.7436 1.2112

B in micro Siemens per mile

5.6990	-1.0817	-1.6905
	5.1795	-0.6588
		5.4246

Configuration 603:

Z (R +jX) in ohms per mile

0.0000 0.0000	0.0000 0.0000	0.0000 0.0000
	1.3294 1.3471	0.2066 0.4591
		1.3238 1.3569

B in micro Siemens per mile

0.0000	0.0000	0.0000
	4.7097	-0.8999
		4.6658

Configuration 604:

Z (R +jX) in ohms per mile

1.3238 1.3569	0.0000 0.0000	0.2066 0.4591
	0.0000 0.0000	0.0000 0.0000
		1.3294 1.3471

B in micro Siemens per mile

4.6658	0.0000	-0.8999
	0.0000	0.0000
		4.7097

Configuration 605:

Z (R +jX) in ohms per mile

0.0000 0.0000	0.0000 0.0000	0.0000 0.0000
	0.0000 0.0000	0.0000 0.0000
		1.3292 1.3475

B in micro Siemens per mile

0.0000	0.0000	0.0000
	0.0000	0.0000
		4.5193

Configuration 606:

Z (R +jX) in ohms per mile

0.7982 0.4463	0.3192 0.0328	0.2849 -0.0143
	0.7891 0.4041	0.3192 0.0328
		0.7982 0.4463

B in micro Siemens per mile

96.8897	0.0000	0.0000
	96.8897	0.0000
		96.8897

Configuration 607:

Z (R +jX) in ohms per mile

1.3425 0.5124	0.0000 0.0000	0.0000 0.0000
	0.0000 0.0000	0.0000 0.0000
		0.0000 0.0000

B in micro Siemens per mile

88.9912	0.0000	0.0000
	0.0000	0.0000
		0.0000

IEEE 38-node system data:

```
Distribution System data (21 bus system)
% Bus Bus   Voltage Angle ---Load---- -------Generator----- Injected
% No code    Mag.  Degree MW     Mvar    MW  Mvar Qmin Qmax      Mvar

busdata=[1  1   1   0   0   0   0   0   0   0   0   1
2   0   1   0   0.1     0.06    0   0   0   0   0   1
3   0   1   0   0.09    0.04    0   0   0   0   0   1
4   0   1   0   0.12    0.08    0   0   0   0   0   1
5   0   1   0   0.06    0.03    0   0   0   0   0   1
6   0   1   0   0.06    0.02    0   0   0   0   0   1
7   0   1   0   0.2     0.1     0   0   0   0   0   1
8   0   1   0   0.2     0.1     0   0   0   0   0   1
9   0   1   0   0.06    0.02    0   0   0   0   0   1
10  0   1   0   0.06    0.02    0   0   0   0   0   1
11  0   1   0   0.045   0.03    0   0   0   0   0   1
12  0   1   0   0.06    0.035   0   0   0   0   0   1
13  0   1   0   0.06    0.035   0   0   0   0   0   1
14  0   1   0   0.12    0.08    0   0   0   0   0   1
15  0   1   0   0.06    0.01    0   0   0   0   0   1
16  0   1   0   0.06    0.02    0   0   0   0   0   1
17  0   1   0   0.06    0.02    0   0   0   0   0   1
18  0   1   0   0.09    0.04    0   0   0   0   0   1
19  0   1   0   0.09    0.04    0   0   0   0   0   1
20  0   1   0   0.09    0.04    0   0   0   0   0   1
21  0   1   0   0.09    0.04    0   0   0   0   0   1
22  0   1   0   0.09    0.04    0   0   0   0   0   1
23  0   1   0   0.09    0.05    0   0   0   0   0   1
24  0   1   0   0.42    0.2 0   0   0   0   0   1
25  0   1   0   0.42    0.2 0   0   0   0   0   1
26  0   1   0   0.06    0.025   0   0   0   0   0   1
27  0   1   0   0.06    0.025   0   0   0   0   0   1
28  0   1   0   0.06    0.02    0   0   0   0   0   1
29  0   1   0   0.12    0.07    0   0   0   0   0   1
30  0   1   0   0.2     0.6     0   0   0   0   0   1
31  0   1   0   0.15    0.07    0   0   0   0   0   1
32  0   1   0   0.21    0.1     0   0   0   0   0   1
33  0   1   0   0.06    0.04    0   0   0   0   0   1
34  0   1   0   0       0       0   0   0   0   0   1
35  0   1   0   0       0       0   0   0   0   0   1
36  0   1   0   0       0       0   0   0   0   0   1
37  0   1   0   0       0       0   0   0   0   0   1
38  0   1   0   0       0       0   0   0   0   0   1];
```

```
%                        Line code
%  Bus bus   R      X     1/2 B   = 1 for lines
%   nl  nr  p.u.   p.u.   p.u.     > 1 or < 1 tr. tap at bus nl

linedata=[1  2   0.000574    0.000293    0   1
         2   3   0.00307     0.001564        0   1
         3   4   0.002279    0.001161    0   1
         4   5   0.002373    0.001209    0   1
         5   6   0.0051      0.004402    0   1
         6   7   0.001166    0.003853    0   1
         7   8   0.00443     0.001464    0   1
         8   9   0.006413    0.004608    0   1
         9   10  0.006501    0.004608    0   1
         10  11  0.001224    0.000405    0   1
         11  12  0.002331    0.000771    0   1
         12  13  0.009141    0.007192    0   1
         13  14  0.003372    0.004439    0   1
         14  15  0.00368     0.003275    0   1
         15  16  0.004647    0.003394    0   1
         16  17  0.008026    0.010716    0   1
         17  18  0.004558    0.003574    0   1
         2   19  0.001021    0.000974    0   1
         19  20  0.009366    0.00844     0   1
         20  21  0.00255     0.002979    0   1
         21  22  0.004414    0.005836    0   1
         3   23  0.002809    0.00192     0   1
         23  24  0.005592    0.004415    0   1
         24  25  0.005579    0.004366    0   1
         6   26  0.001264    0.000644    0   1
         26  27  0.00177     0.000901    0   1
         27  28  0.006594    0.005814    0   1
         28  29  0.005007    0.004362    0   1
         29  30  0.00316     0 .00161    0   1
         30  31  0.006067    0.005996    0   1
         31  32  0.001933    0.002253    0   1
         32  33  0.002123    0.003301    0   1
         8   34  0.012453    0.012453    0   1
         9   35  0.012453    0.012453    0   1
         12  36  0.012453    0.012453    0   1
         18  37  0.003113    0.003113    0   1
         25  38  0.003113    0.003113    0   1];
```